Electric vehicles (PHEV and BEV) in the German electricity system

Berkeley 2009.08.17

David Dallinger

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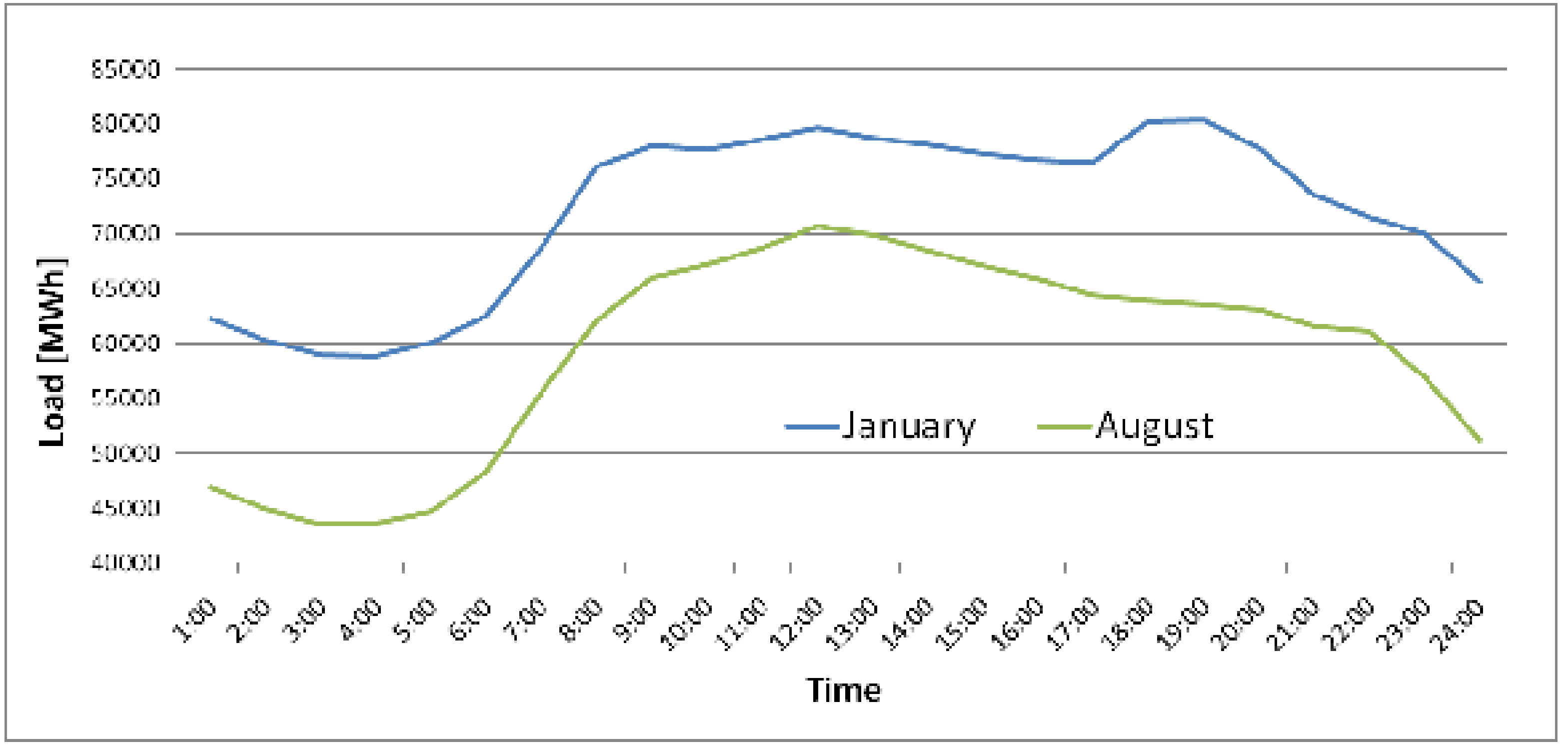
The German situation

Total system load (Germany)



- The peak load is during winter time (approx. 80 GW)
- Minimal load is during summer time in the night (approx.45 GW)

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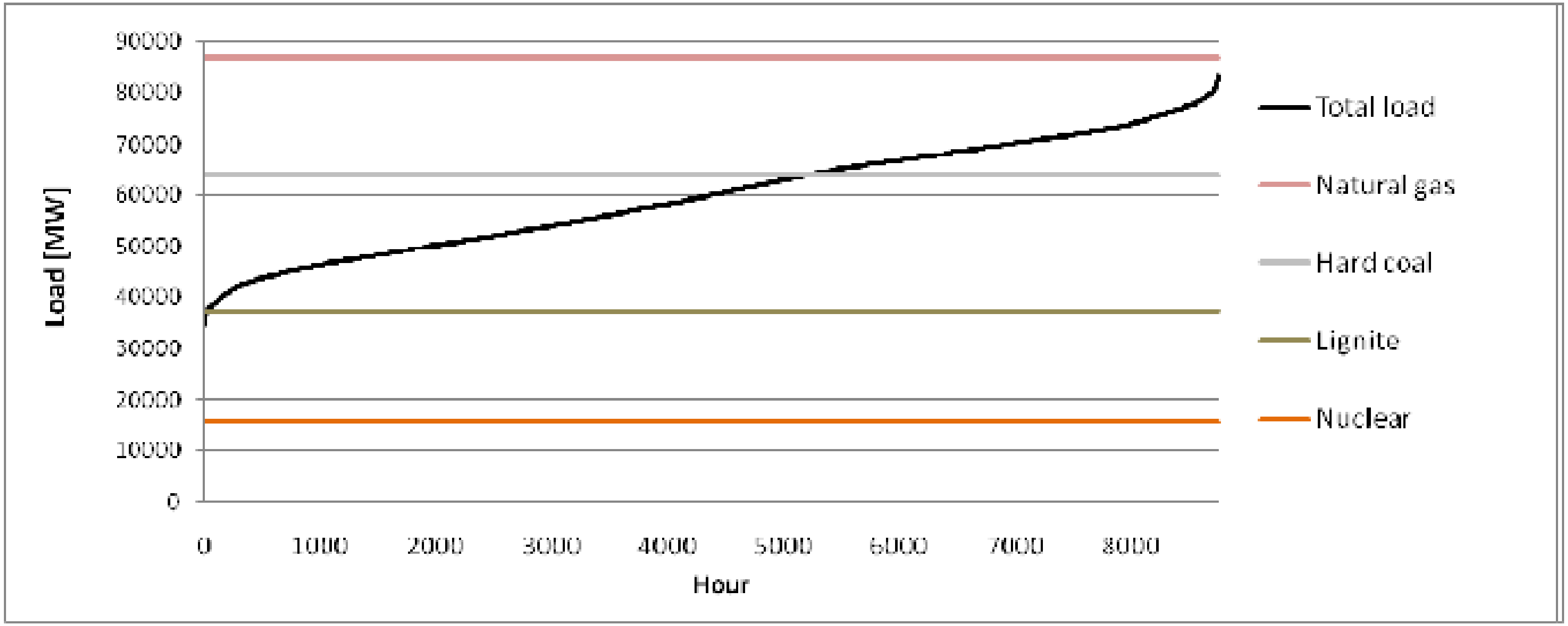
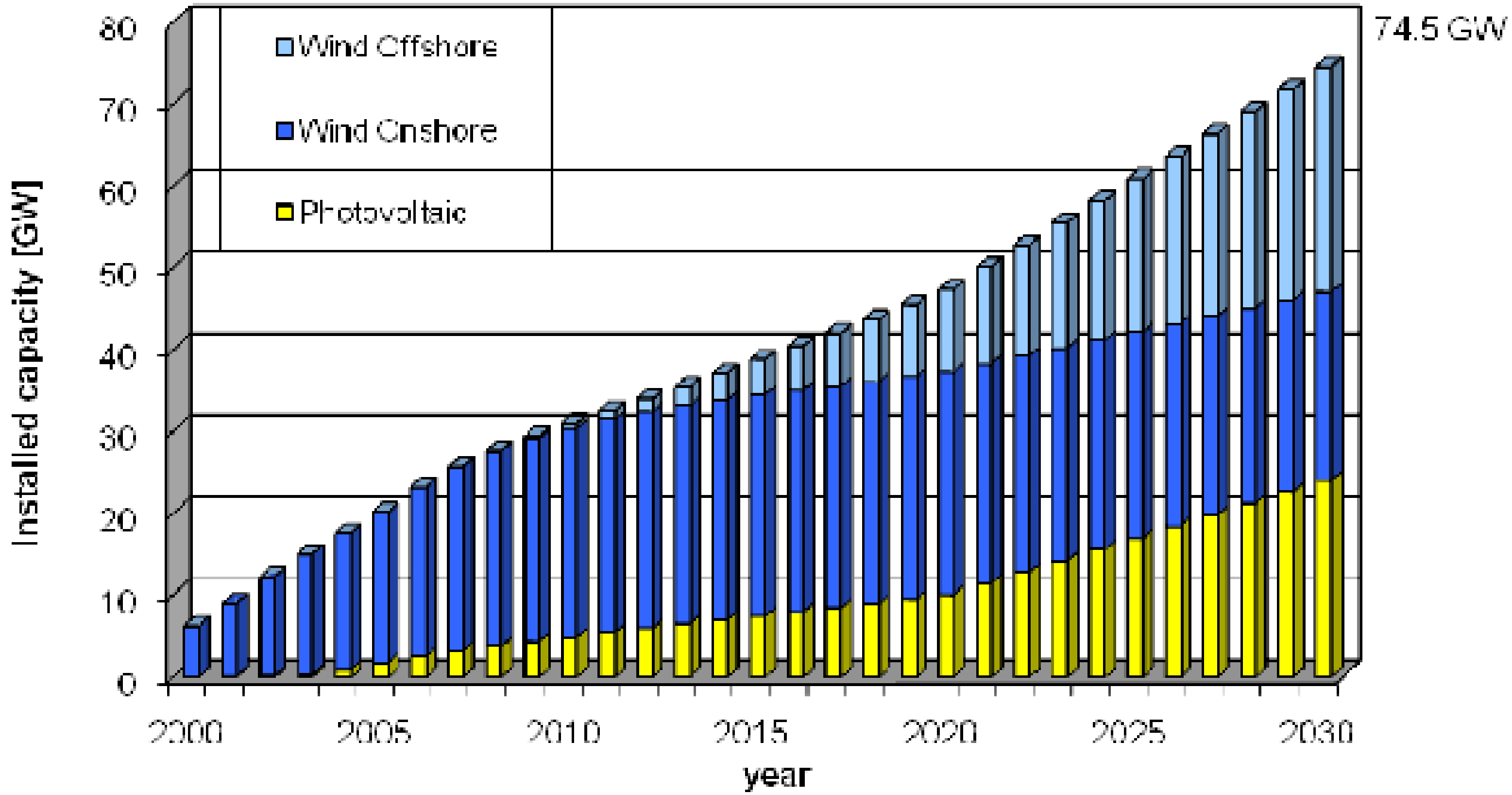
Energy mix of thermal power plants



Capacity of fluctuating renewables



Reference: Nitsch J., DLR Abteilung „Systemanalyse und Technikbewertung“ (2008) Leitstudie 2007„Ausbaustrategie Erneuerbare Energien“, Untersuchung im Auftrag des Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit.

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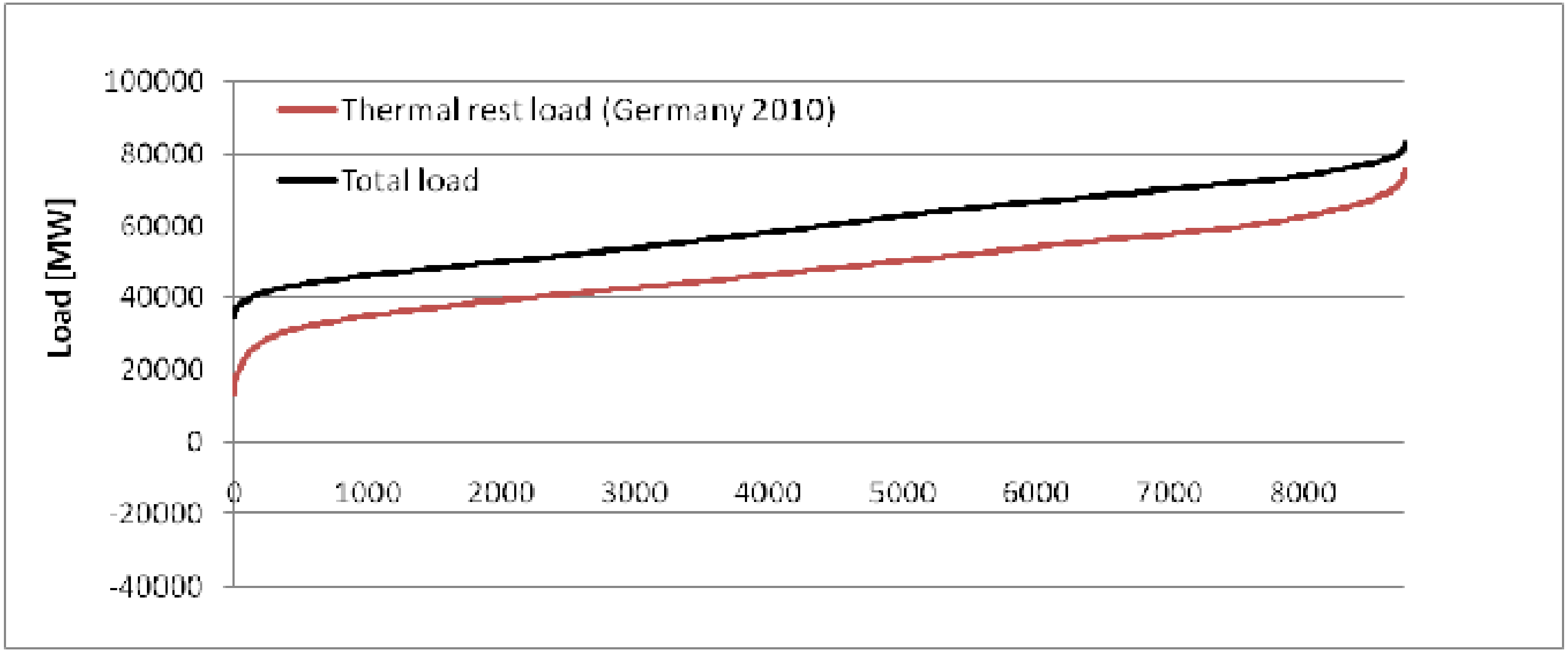
Thermal Rest Load



- Thermal rest load is defined as the system load minus the renewable load
- Thermal rest load ranges from 18 GW to 77 GW in 2010

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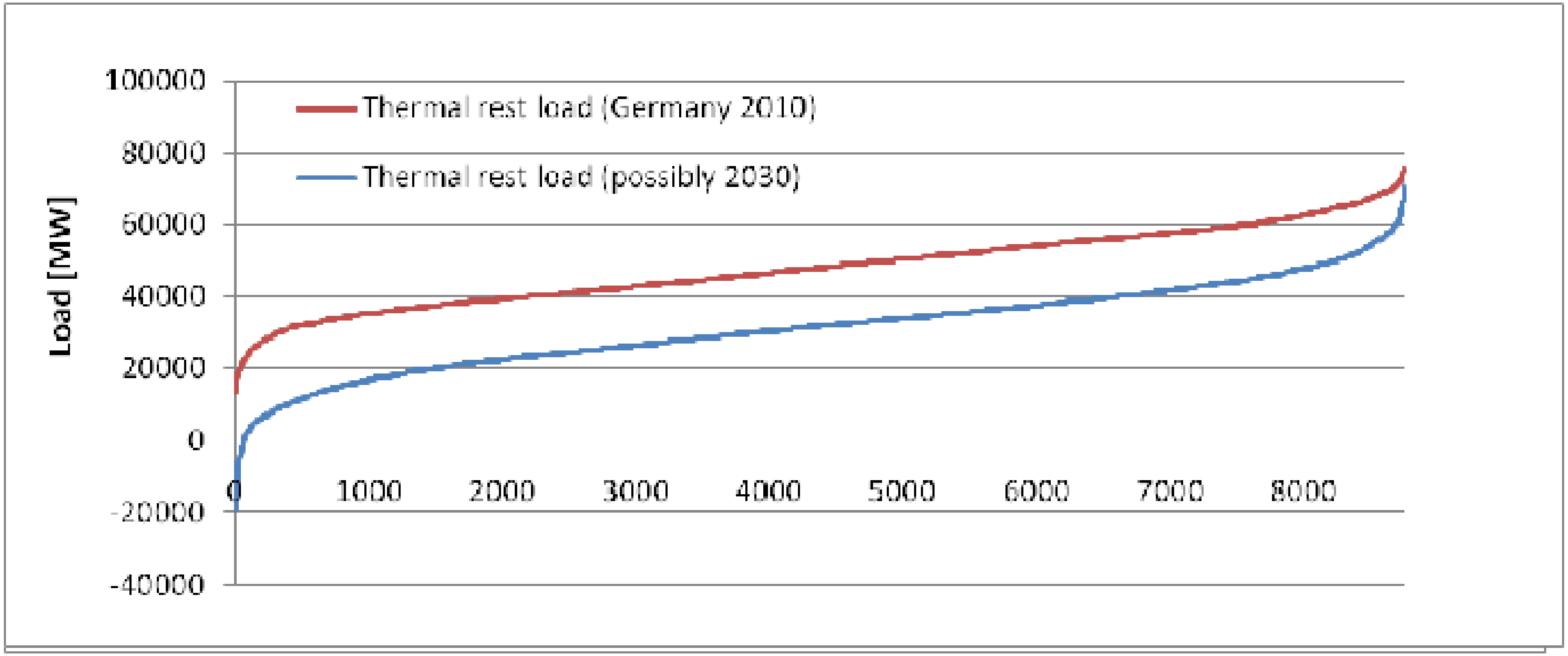
Thermal Rest Load



- Scenarios for 2030
- “Negative” thermal rest load: Renewable generation > System Load
- “Negative” thermal load could occur for 10 to 100 hours in the future

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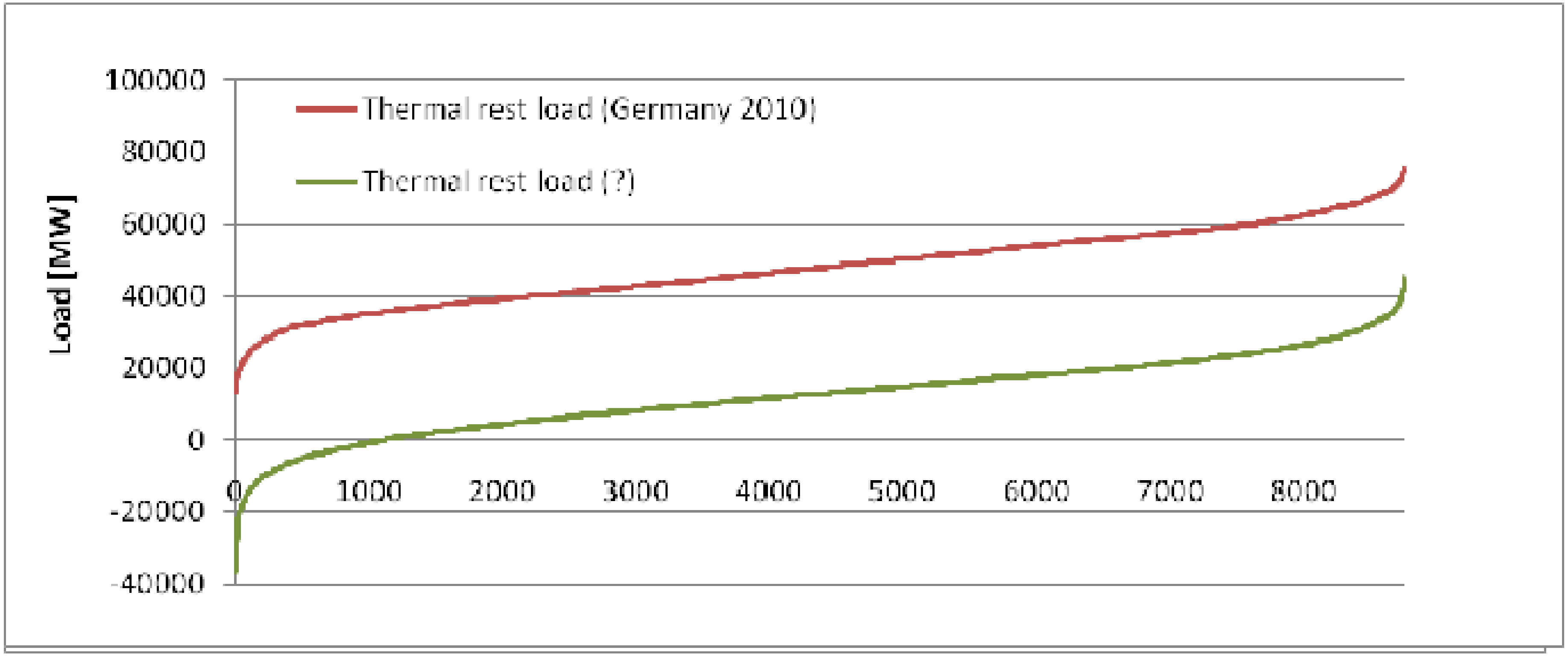
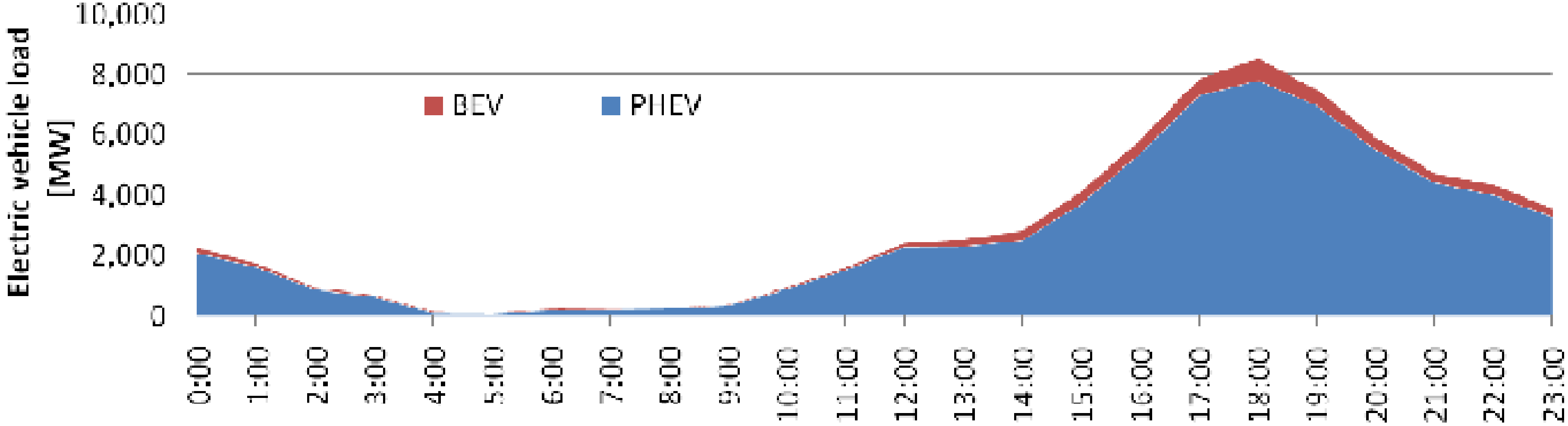
Thermal Rest Load



- Scenario: Load reduction due to a more efficient use of electricity
- Thermal rest load could drop to a range from -36 GW to 45 GW
- “Negative” thermal load could occur for 100 to 1000 hours in the future

Load of electric vehicles (charging after the last trip)



Load curve of electric vehicles charging after the last trip on Friday

(Data driving behavior: Mobility in Germany (MID) 2003)

Assumptions: 3.68 kWh grid conection; 85% efficency battery charging; electric vehicles (approx.11 Mio.), thereof:

- 92.5 % PHEV: 50 km electr. range and 0.16 KWh energy use per km
- 7.5 % City-BEV: 100 km electr. range and 0.11 kWh energy use per km

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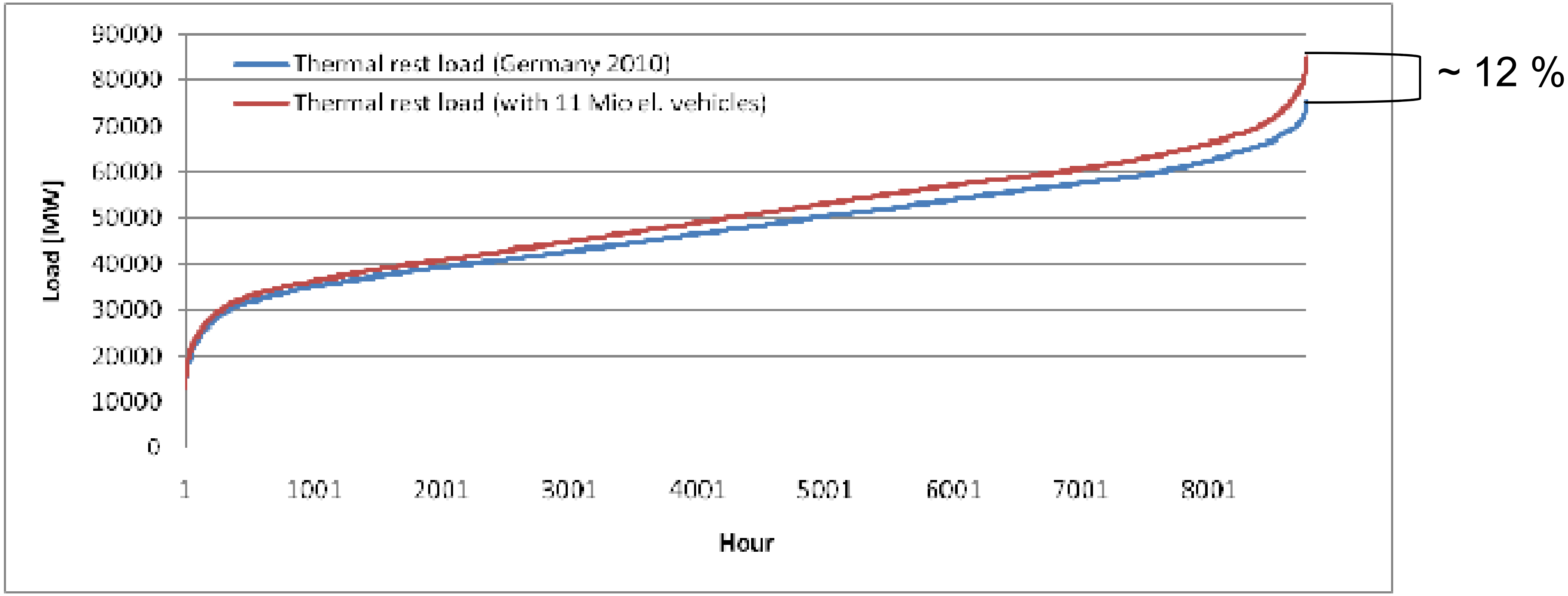
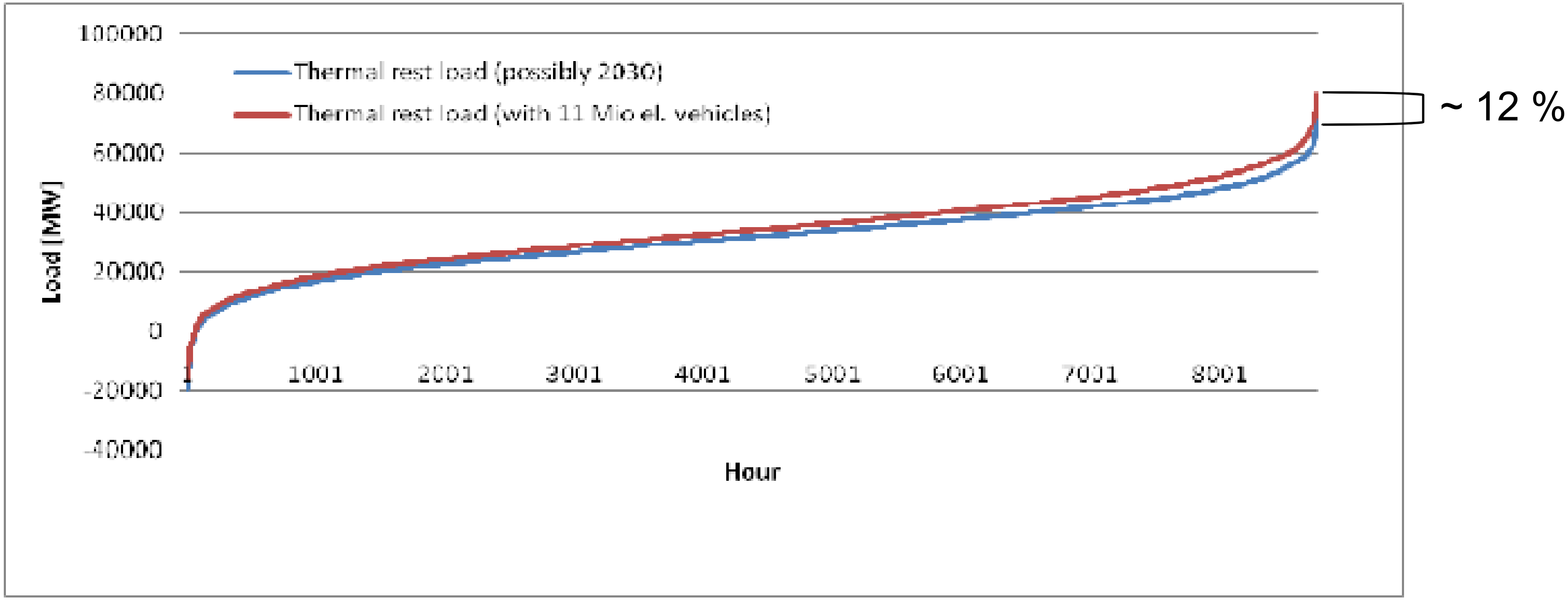
Effect of PHEVs and BEVs on the system load curves (2010)



- Additional peak load: 12 % or 9 GW (capacity less than 500 full load hours 10.8 GW vs. 16.3 GW)
- Marginal CO_2 emissions: 877 g/ kWh (as expected for 2010 conditions)
- Vehicle CO_2 emissions: 175 g/ km (0.2 kWh/km x 877 g / kWh)

Effect of PHEVs and BEVs on the system load curves (2030)



- Additional peak load 12 % or 9 GW (capacity less than 500 full load hours 20.3 GW vs. 24.6 GW)
- Marginal CO_2 emissions: 472 g/ kWh
- Vehicle CO_2 emissions: 94 g/km (0.2 kWh / km x 472 g / kWh) vs. wind power 10 g/km (0.2 kWh / km x 50 g / kWh)

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Indirect control of plug-in hybrid vehicles with variable tariffs

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Strategies controlling grid connected vehicles

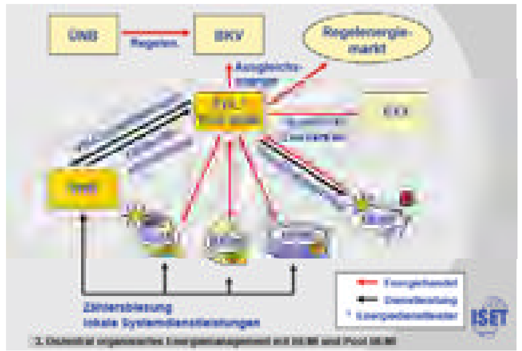
Direct control

Prompt and predictable reaction on control signals
Reduced residential consumer acceptance
High communication effort

DEMS Dezentrales Energiemanagement System (Siemens)

Indirect control

Price signals (CPP, TOU, RTP)
The consumer decides
Prediction of consumers reaction on different price signal
Possibility to forecast errors



BEMI Bidirectional Energy Management Interface (ISET)

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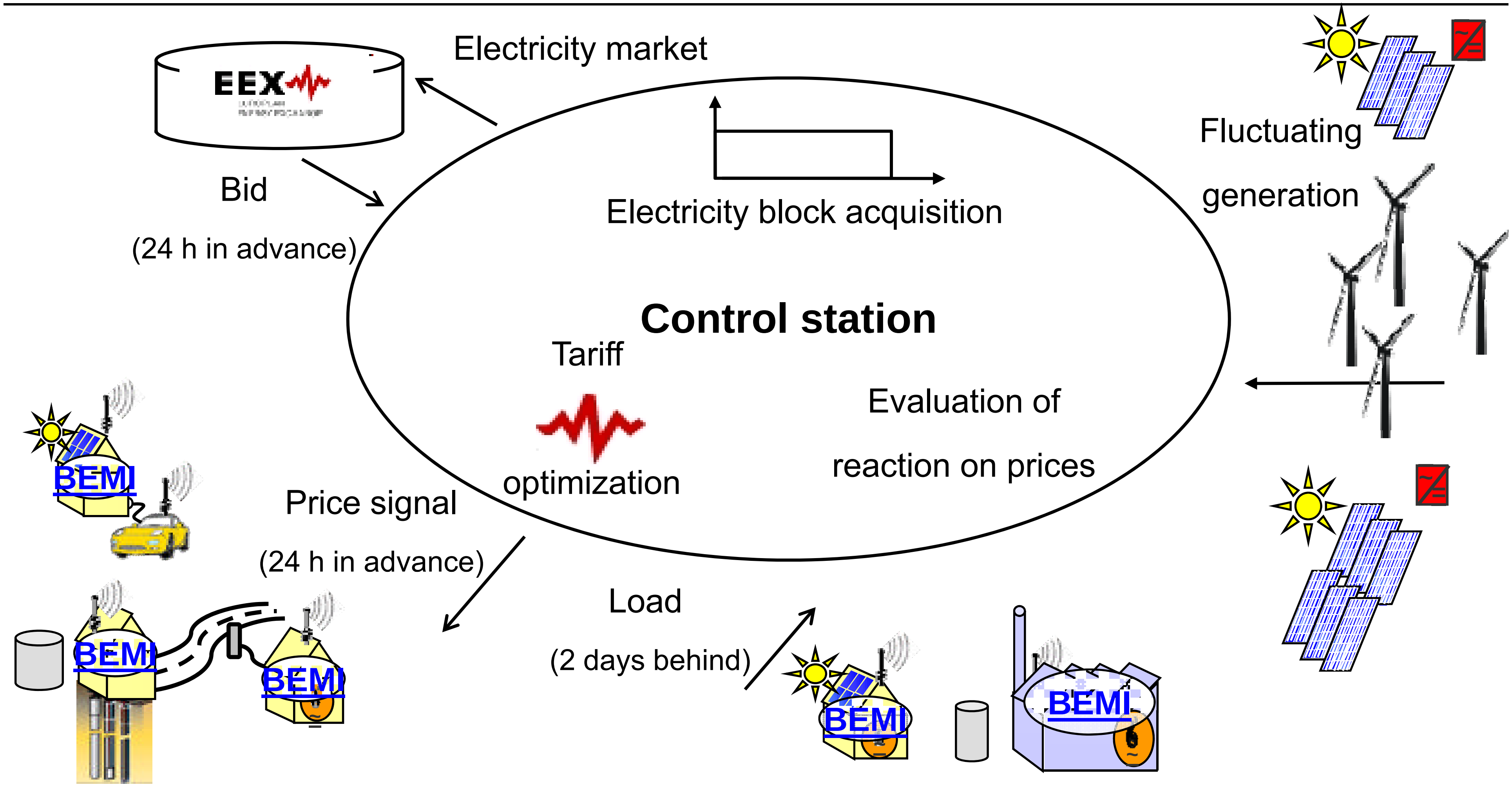
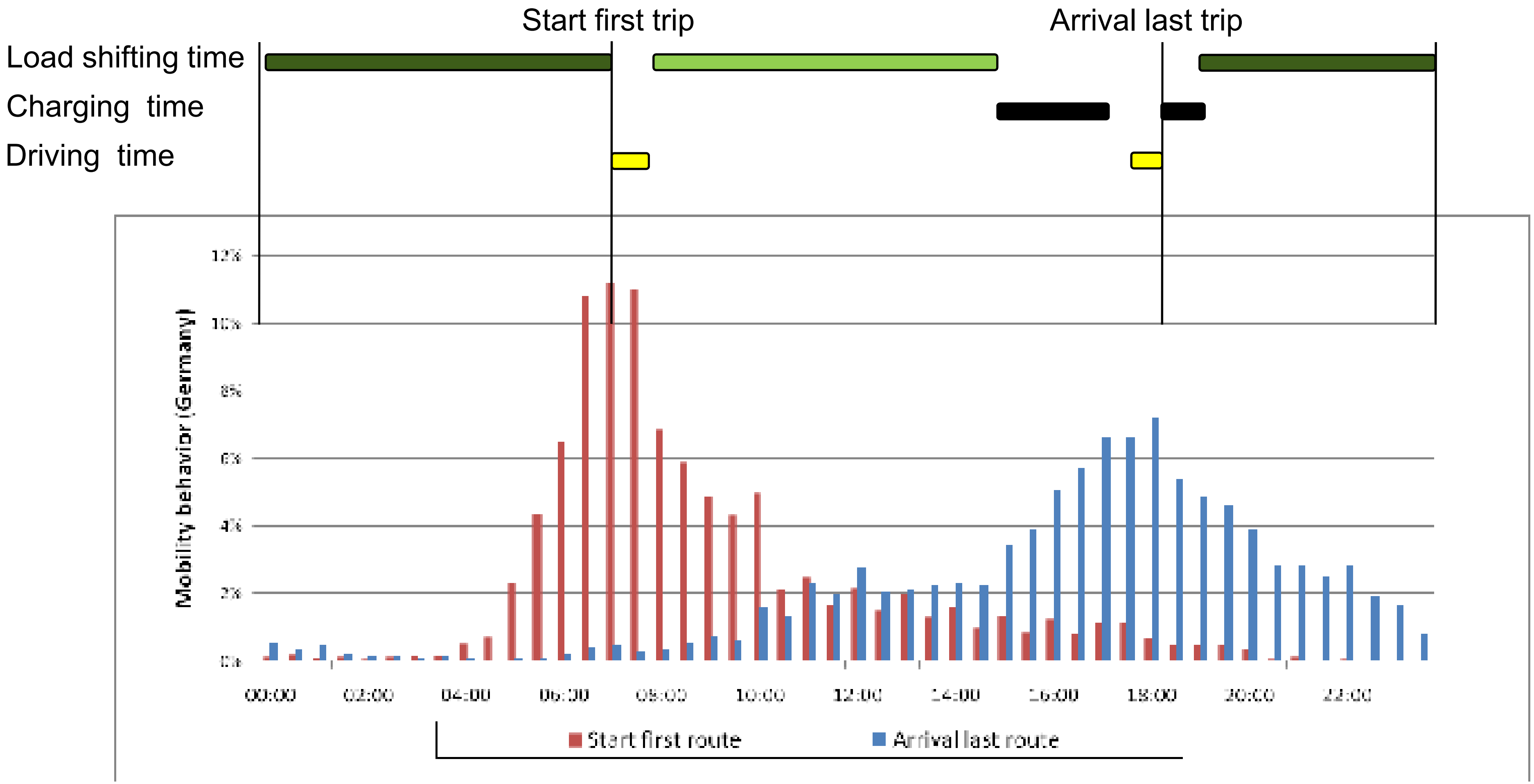
Principles of BEMI energy management with variable tariffs



Load shifting potential



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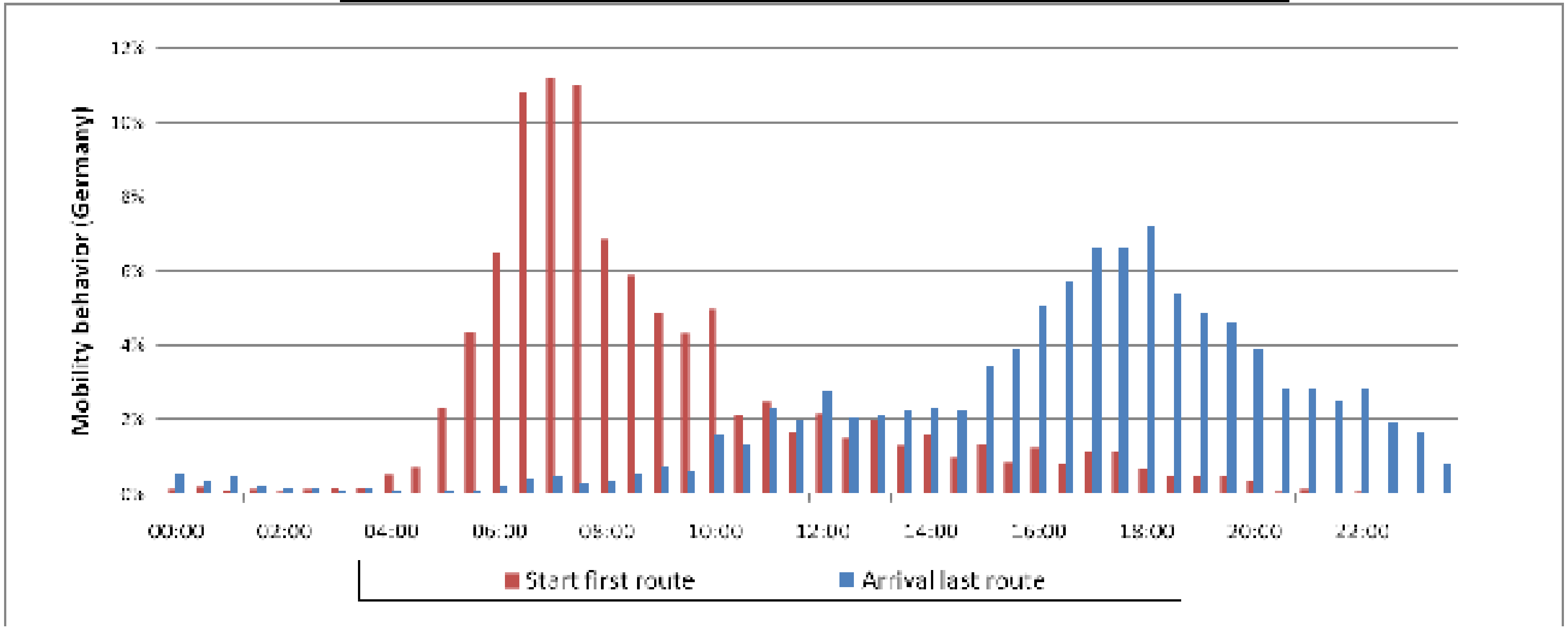
Load shifting potential

[hour: minute]	During daytime Mo. – Thur.	During night time
Full- time employee	5:15	12:17
Unused vehicles [%]	30	-



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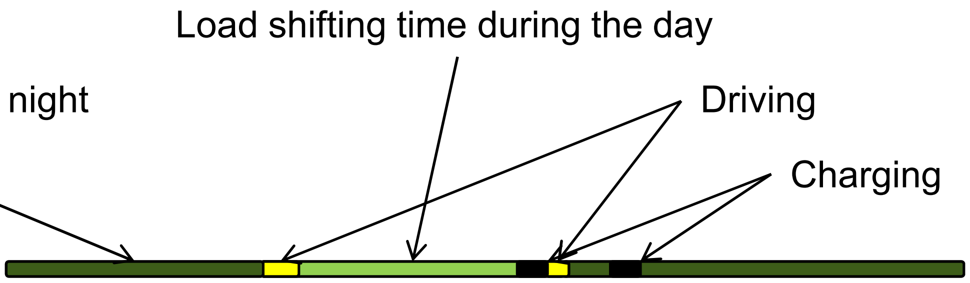
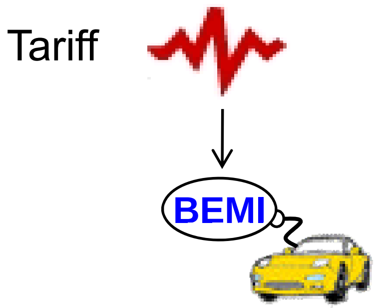
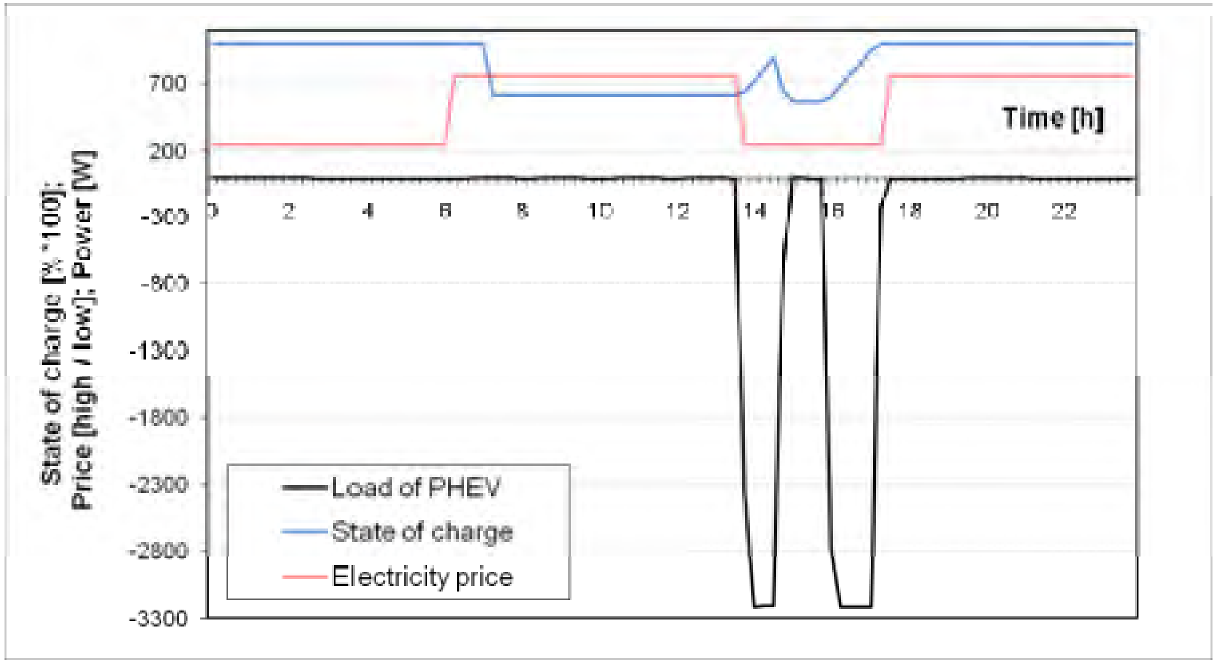
Automatic control of electric vehicles

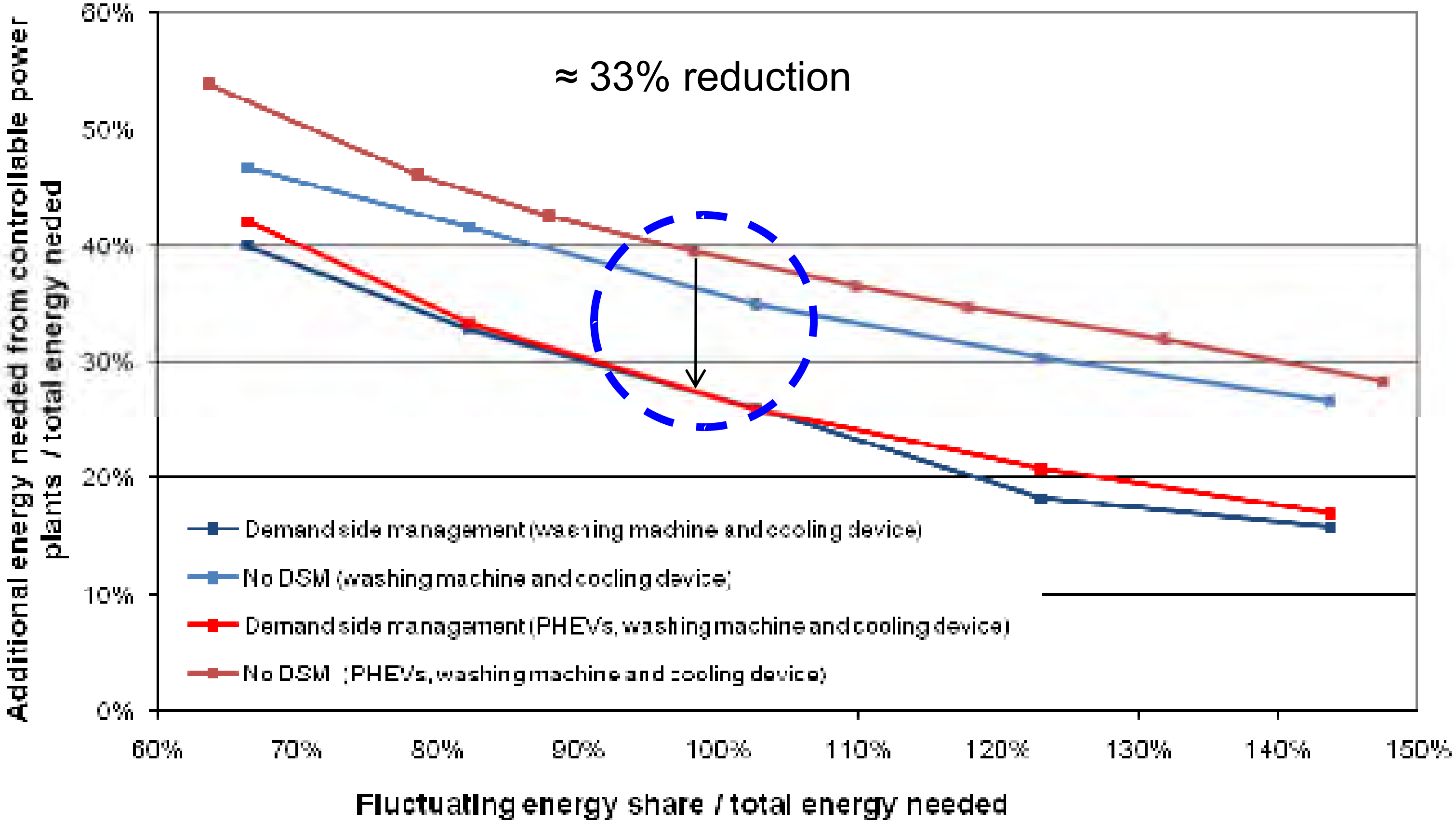


Control station





Prospects for the integration of fluctuating renewable energies



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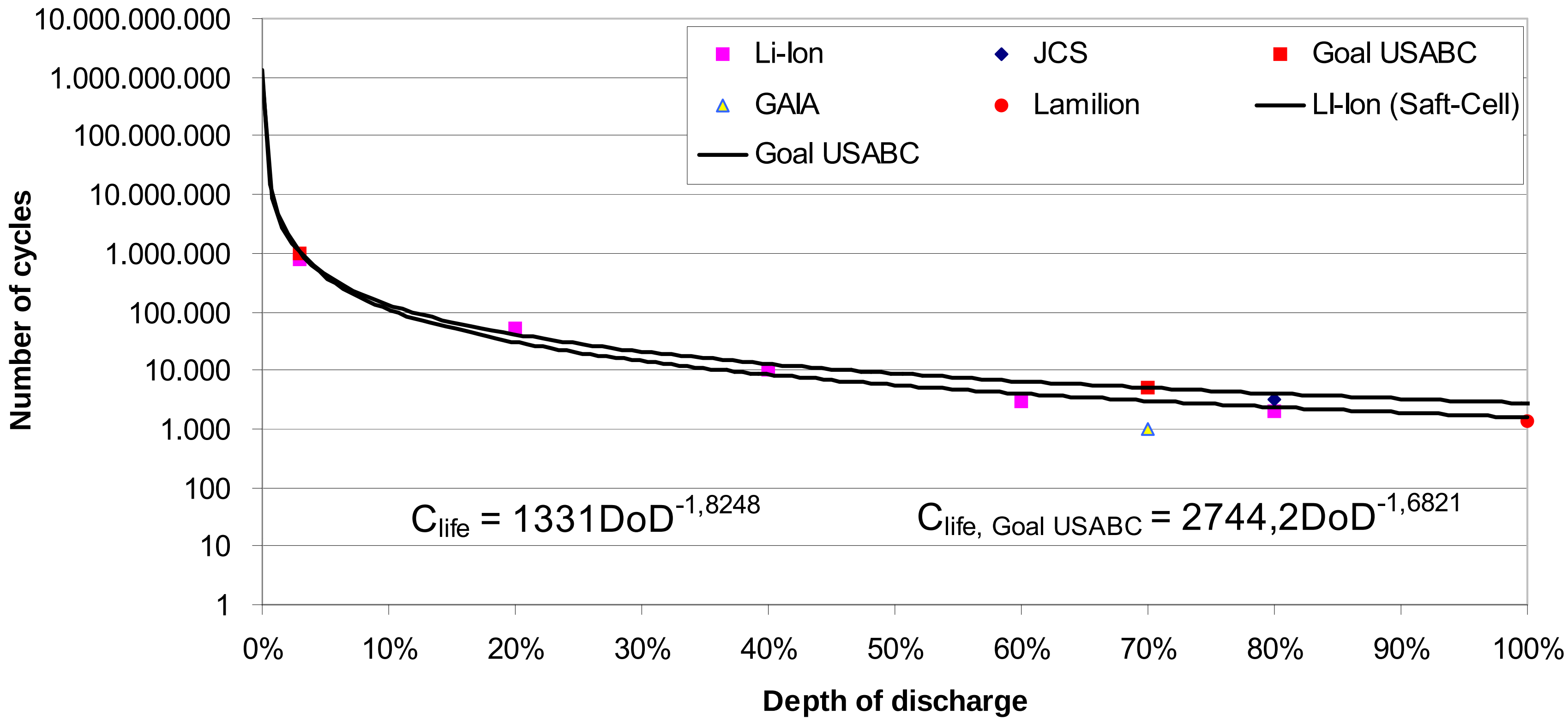
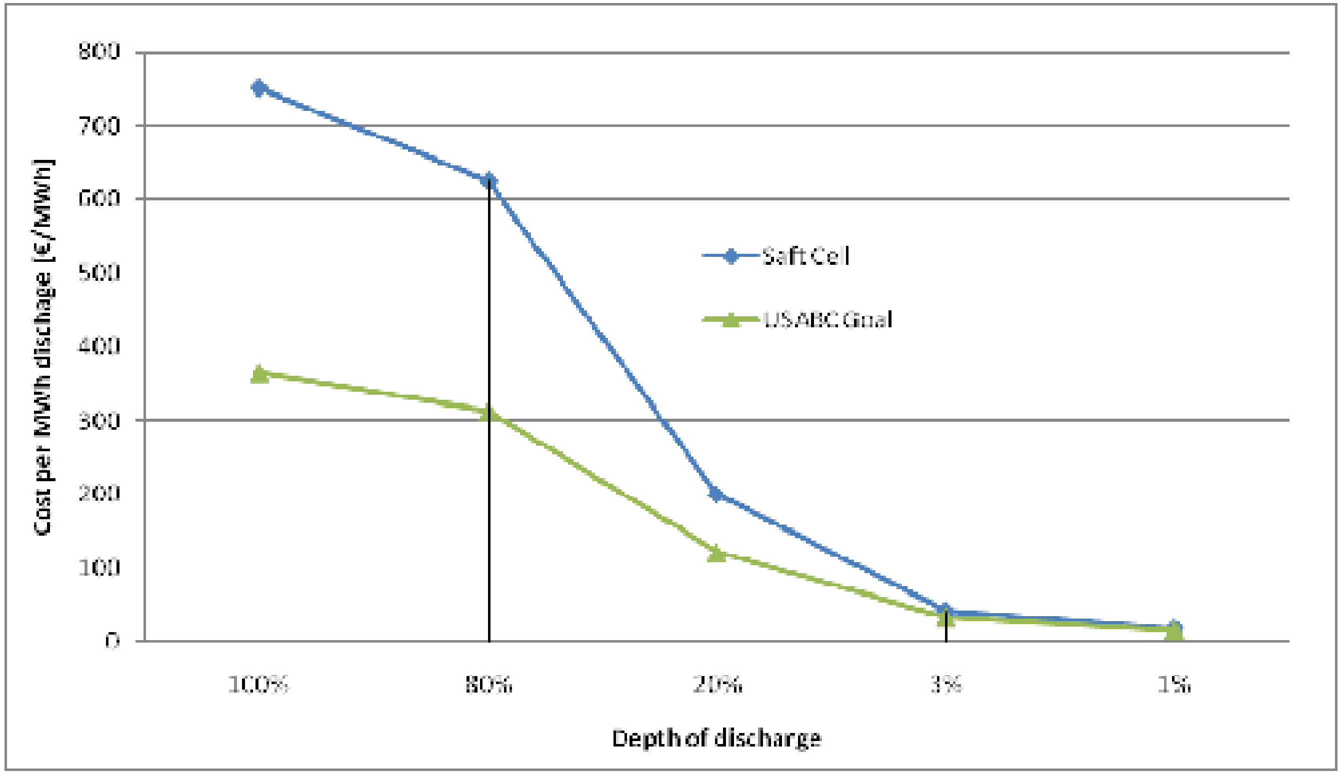
V2G?

Cycle lifetime of lithium batteries



Battery discharge costs



Assumptions:

Current battery investment costs (Saft cell): 1000 €/ kWh (Saft cell)

Future battery investment costs: 350 €/ kWh (USABC goal)

PHEV profit from ancillary services

PHEV		primary control	secondary control positive	secondary control	tertiary control positive	tertiary control
Offered Power	P_{Fzg}	1.92 kW	2.58 kW	1.15 kW	2.58 kW	1.15 kW
Depth of discharge V2G	DoD_{V2G}	3%	47%	-	2%	-
Income ancillary services (power)	r_{cap}	191.95 €	130.19 €	31.02 €	56.38 €	12.12 €
Income ancillary services (energy)	r_{el}	-	98.63 €	195.20 €	10.18 €	20.18 €
Total income	$\mathbf{r_{reg}}$	**191.95 €**	**228.82 €**	**226.22 €**	**66.56 €**	**32.30 €**
Fixed costs	c_{fix}	43.80 €	54.88 €	11.28 €	54.88 €	11.28 €
Variable costs	c_{var}	12.03 €	402.66 €	-	13.65 €	-
Total cost	$\mathbf{c_{reg}}$	**55.83 €**	**457.54 €**	**11.28 €**	**68.53 €**	**11.28 €**
Profit / disprofit		**136.12 €**	**-228.72 €**	**214.94 €**	**-1.97 €**	**21.02 €**

Estimation of the profit from anciliary services per year.

primary control : frequency-response reserve
secondary control: spinning and non spinning reserves tertiary control replacement reserve

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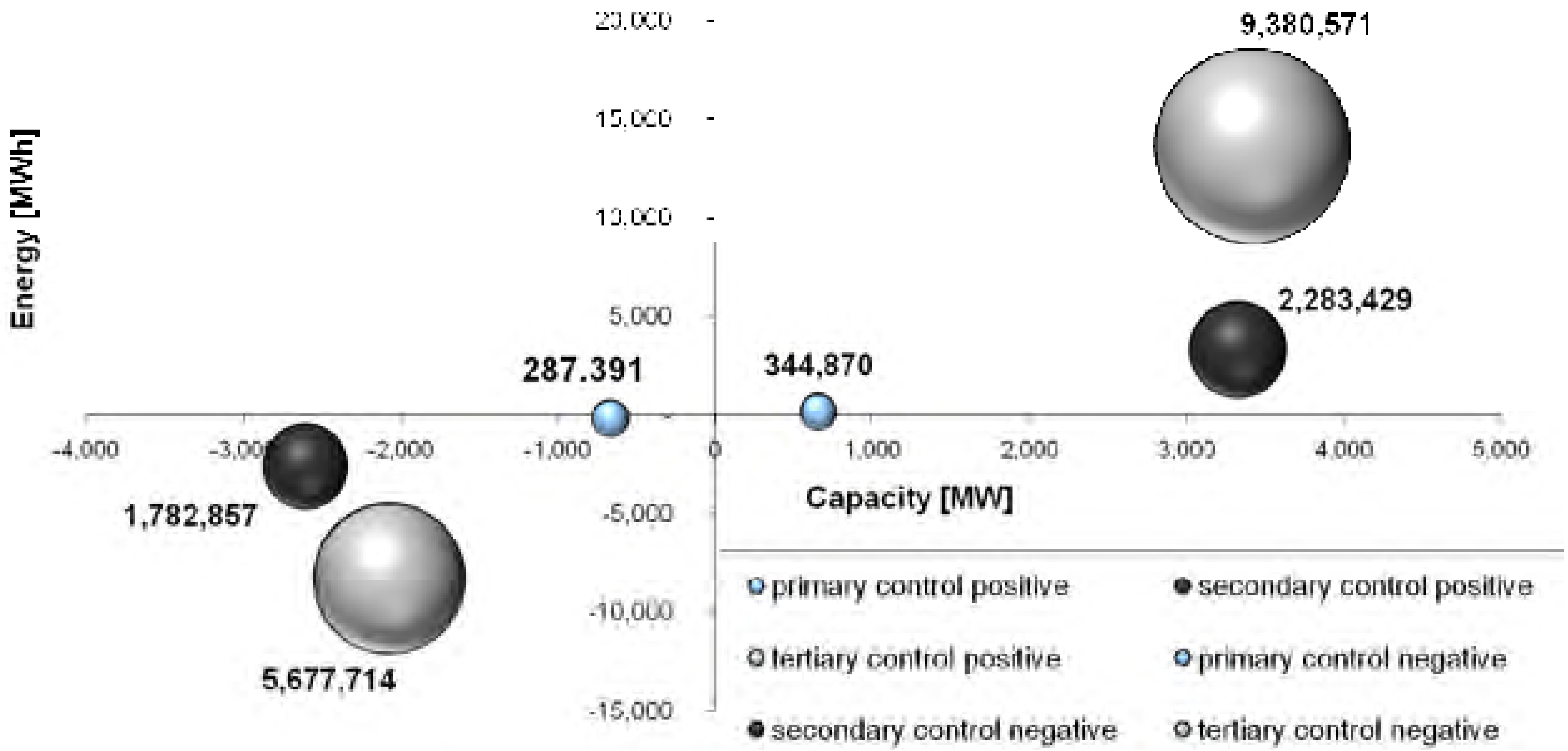
Volume of ancillary markets



primary control : frequency-response reserve
secondary control: spinning and non spinning reserves tertiary control replacement reserve

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Thank you for your attention !

Acknowledgements:

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First German offshore wind turbine (http://www.alpha-ventus.de/)

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Ongoing projects

MEREGIO*mobil*
(Fleet test)
business models,
control (real-time pricing)
and customer acceptance
for smart home and
decentral generation

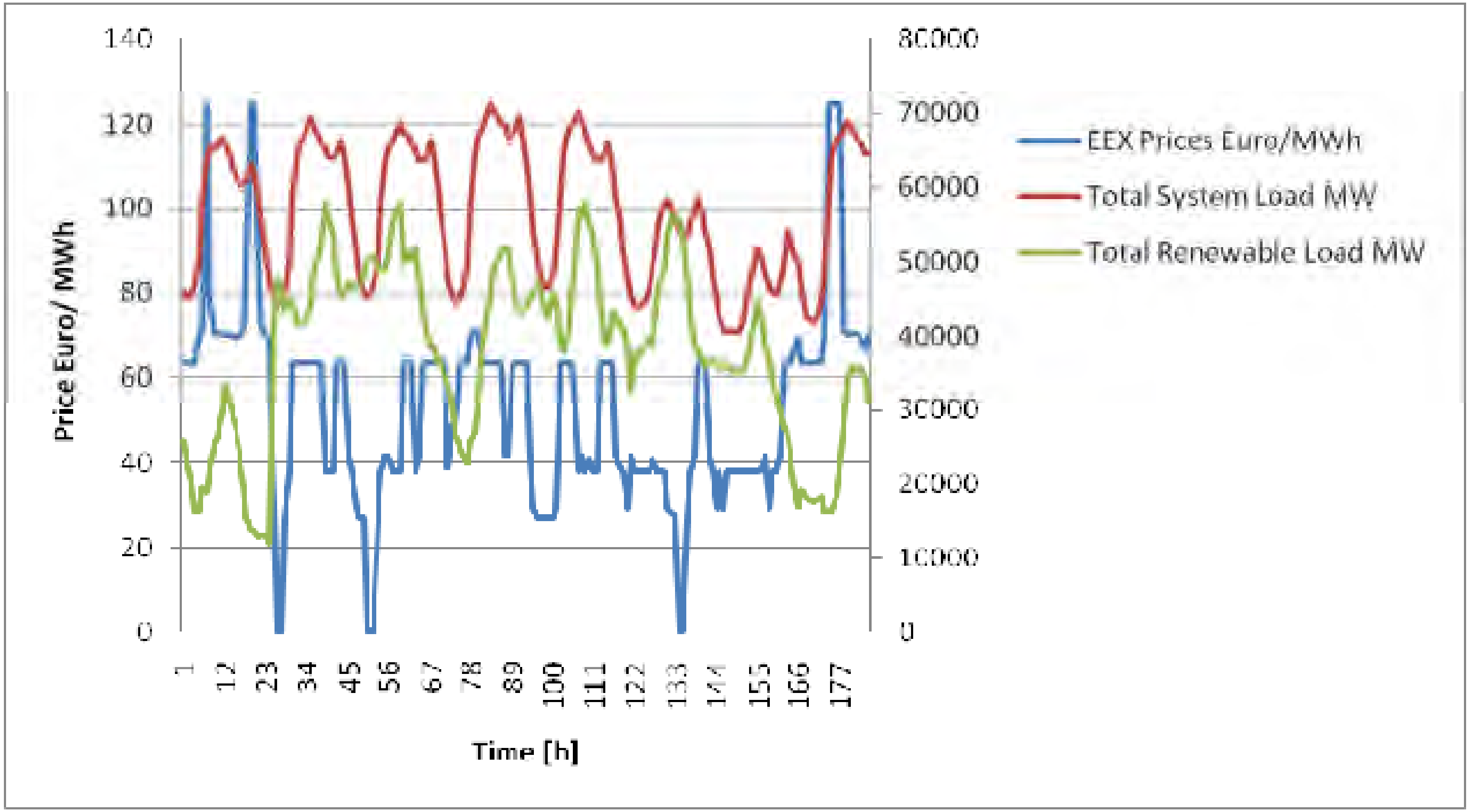
Electromobility Fleet Test
improved integration of
renewable energies into
the electricity system
by electric vehicles

Fraunhofer Systems Research Electromobility
concomitant socio-economic study,
34 institutes looking at all
aspects of electric vehicles
and grid-integration

Further
traffic-economic studies
for EU
(IEKP-monitoring)

LIB 2050
concomitant study on
lithium-ion battery
development
(Roadmap)

Electricity price



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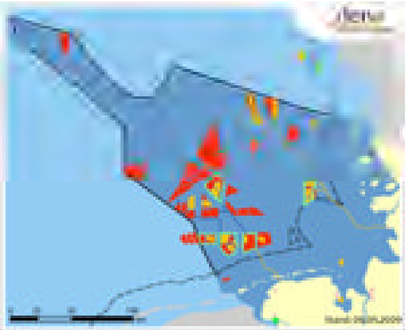
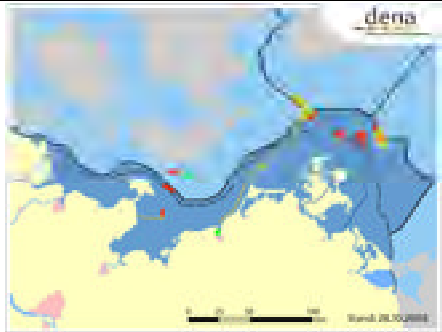
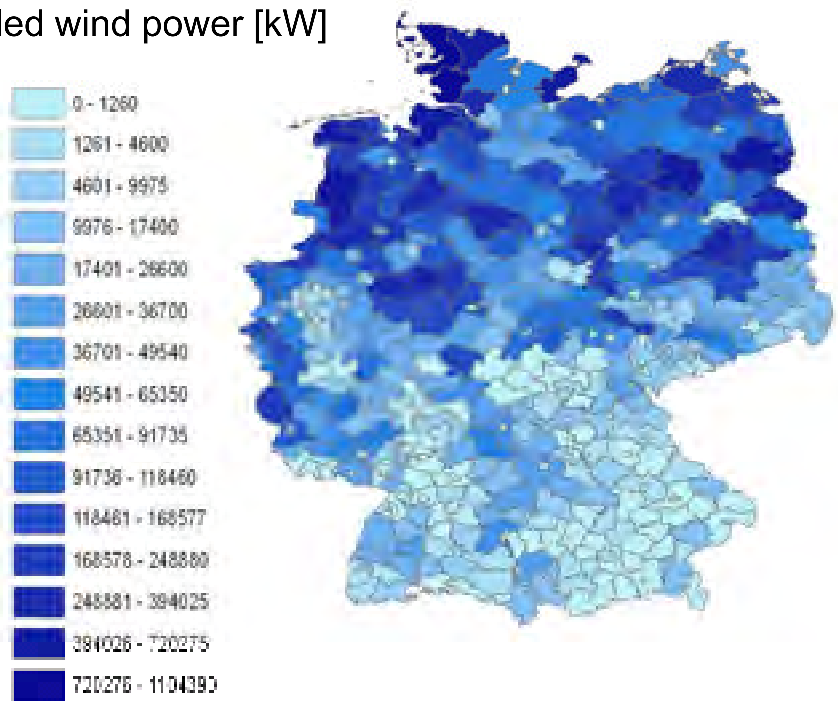
Wind power in Germany





installed wind power [kW]



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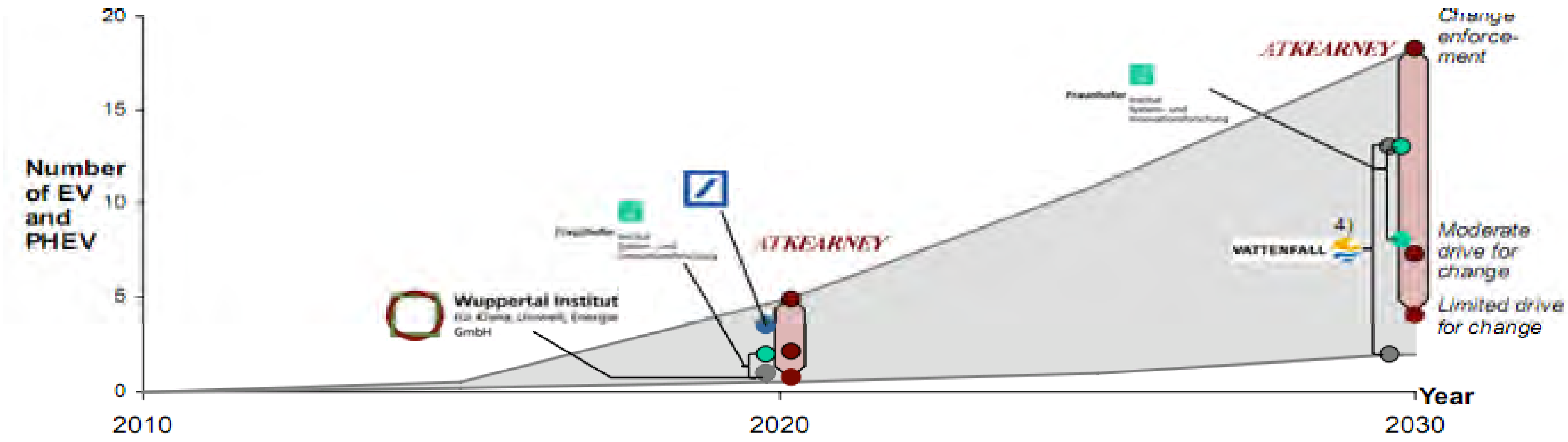
Expected market penetration of electric mobility

start of 4von vier fleet tests,

more tests in preparation

announcement by car companies:
12 electric car models in the market until 2012

survey on electric vehicles in 2020
- Goal of German Federal Government: 1 Mio.
- Estimate of A.T.KERNEY: 0 – 5 Mio.
- Estimate of Fraunhofer-ISI: 0.4 – 1.8 Mio.



Reference: AT Kearney

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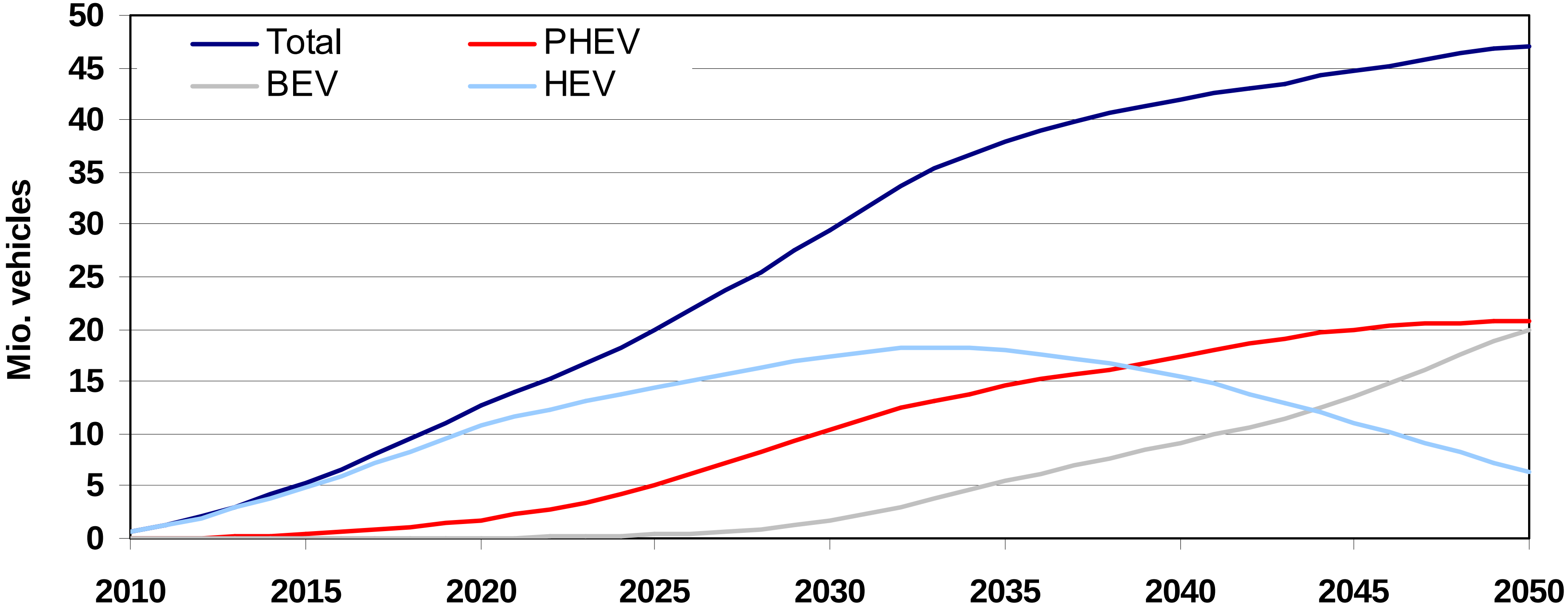

Reference: METI (2006): "Strategic Technology Roadmap (Energy Sector) – Energy Technology Vision 2100". Ministry of Economy, Trade and Industry, Japan.

Indirect control of plug-in hybrid vehicles with variable tariffs

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Abstract:

This paper examines whether the load profile of plug-in hybrid vehicles (PHEVs) can be controlled by an indirect energy management system based on variable electricity tariffs. The main purpose is to analyse the potential contribution of PHEVs to integrating high shares of fluctuating energy, e.g. from wind power and photovoltaics (PV), into the electric grid.

The study is based on an energy management system developed by the Institute of Solar Energy Technology (ISET). This system combines demand-side management with generation management[1] in the low-voltage grid and has already been proven in a field test[2]. To investigate the scale-up of the management system from single to multiple grid connection points, a simulation is used based on the algorithms applied in the realized system. Triggered by a price signal, every customer optimises local devices and the charging profile of his or her PHEV automatically using a Bidirectional Energy Management Interface (BEMI) as the local energy management system. A centrally managed control station statistically evaluates the reactions of the customers to different price signals and then generates the price signals for the following day according to the price reaction and the predicted supply of energy from wind and PV[3]. This method encourages participants to use energy in periods characterised by a high supply from fluctuating energy sources and to reduce the electricity required from controllable power plants. In earlier publications[4], simulations have already shown for households equipped with washing machines and refrigerators that

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1 Currently, generation management is used for combined heat and power plants. In the simulation PHEVs are implemented as loads.

2 [Bendel, 2007]

3 German wind and PV power production figures are provided by ISET and represent conditions in 2006.

4 [Nestle, 2008]

the demand-side management system can reduce the energy required per year from controllable power plants by up to 30 % in electricity systems with a high share (100 %) of intermittent supply compared to a situation without energy management. An extended simulation including PHEVs shows an even higher reduction potential of up to 33 %[5] .This result proves that it is feasible to use indirect management systems to control electric vehicles. Furthermore, it indicates a high potential for integrating larger shares of intermittent renewable energy into the electricity system.

Introduction

Integrating high shares of fluctuating power generation into the electricity system requires flexible power plants, storages and/ or power distribution via a reliable power grid. In addition, the control of electricity demand with demand response or management can be a solution for a better integration of wind power and PV. There are two main approaches controlling electricity demand. The first approach is direct control. Direct control implies that a service provider can shut down / reduce the power of loads or control decentralized generation units directly. An example for this case is the load control program of Southern California Edison[6], which shifts air condition loads from peak periods, or virtual power plants controlled by direct control systems such as the “Dezentrales Energie Management System” (DEMS) of the German Siemens AG. Advantages of direct control are the prompt and predictable reaction on control signals. Drawbacks arise from the reduced consumer acceptance in the case of controlling loads situated in private homes or private cars and the high communication effort controlling a high number of small storage or generation units. The second approach, indirect control, uses price signals for the control of loads or generation units. In this case the service provider sends price signals and the consumer (or an automatically controlled device programmed by the consumer) decides on either reducing or shifting the load when price is high or just paying the higher price. In this case the consumer acceptance should be higher than in the case of direct control. Disadvantages arise from the fact that it is necessary to predict the reaction of con-

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5 [Dallinger, 2008]

6 [Southern California Edison, 2008]

sumers on different price signal, which yields the possibility of forecast errors. However, since consumer acceptance is crucial for the feasibility of the management of mobility related systems, an indirect energy management system is considered as the most promising option controlling PHEVs.

Method of the decentralized bidirectional energy management

The energy management system designed and implemented by ISET consists of a central control station generating price signals and a local unit installed in homes or businesses. The latter is called "Bidirectional Energy Management Interface" (BEMI). It optimises the energy use or generation according to a price signal (Figure 1).

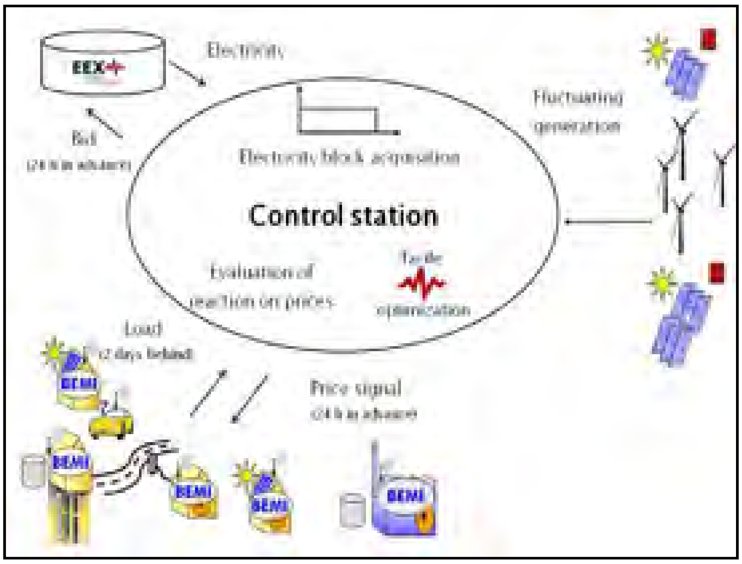

Figure 1: Basic principle of the ISET energy management system

In the approach presented in this work, each price signal adopts a low and a high price value (Figure 2). Different price signal are generated for different groups of BEMIs. This is necessary to avoid avalanche effects that can occur, if all BEMIs switch the devices at the same time when the optimisation is based on the same price signal. To estimate the reaction on different prices the control station analyses the behaviour of each BEMI group. Therefore each BEMI records and sends the power consumed in increments of 15 minutes to the control station. A learning algorithm remembers the reaction on the different price signals. After a phase of learning the control station can estimate the reaction of different groups on prices. This is necessary to distribute the fluctuating power from wind and PV[7] to the customers within the analysis. Thus, the control station balances the electricity generated by fluctuating power plants and the load of different BEMI groups. Knowing the reaction on different prices the control station chooses the price signals to maximize distribution of fluctuating energy. The additionally needed electricity or the surplus generated electricity from fluctuating generation can be traded in blocks at the energy exchange. The balance of the fluctuating electricity generation over the exchange market is not possible and will be realized solely with the described demand-side management system. Additionally required energy should be minimal and indicates the quality of the demand-side management (Figure 6).

Demand-side management with PHEVs:

The BEMI can manage different types of devices[8]. The most important device discussing PHEVs and battery electric vehicles (BEVs) is the storage device or State of Charge (SOC) device. The SOC- device shifts loads (thermal storage units like refrigerators or water heating devices) and/ or generation capacity (such as small combined heat and power plants or fuel cells) in time slots with low and high prices respectively. A PHEV or BEV could be used for load management when charging the vehicle or for generation management, when feeding back electricity (vehicle-to-grid). PHEVs and BEVs are assumed as SOC- devices simply used for load shifting [9].

To estimate the load shifting potential of private vehicles in Germany the public- opinion poll [MID, 2002] is used. This survey consults more than 60,000 people about their mobility behaviour. Eq. 1 gives the maximum load shifting time span during the day:

$$(1)\quad \textit{Load shifting time}_{\textit{during the day}} = t_{(\textit{start first route-arrival last route})} - t_{\textit{driving}} - t_{\textit{charging } n\text{-}1}$$

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7 The control station knows the generation of wind and photovoltaic 24 hours in advance, when the trading on the energy exchange market is arranged. Hence, no prognosis error of the fluctuating power is taken into account.

8 [Nestle, 2008] p. 81

9 Vehicle-to-grid applications are an interesting fact in long term, but will not be addressed in this paper.

Where $t_{(start\ first\ route\text{-}arrival\ last\ route)}$ is the duration between the first and the last route, t_{drive}[10] is the average driving time for all routes and $t_{charging\ n\text{-}1}$[11] is the charging time aside from the last route. The possible time slot for load shifting during the day is smaller compared to the load shifting time during the night as given in Eq.2.

(2) Load shifting time$_{during\ the\ night} = t_{(arrival\ last\ route\ -\ start\ first\ route)} - t_{charging}$

Where $t_{(arrival\ last\ route\ -\ start\ first\ route)}$ is the duration between the last and the first route and $t_{charging}$ is the charging time for the energy used during all routes. Table 1 summarizes the theoretical load shifting potential for selected vehicle users and weekdays.

Table 1: Maximum load shifting times

[hour: minute]	During daytime Mo. – Thur.	During daytime Saturday	During daytime Sunday	During night time
Housewife/ -man	2:55	2:27	2:24	17:25
Retiree	1:41	2:06	1:31	17:24
Part- time employee	3:41	2:36	1:28	14:57
Full- time employee	5:15	2:29	2:11	12:17
Unused vehicles [%]	30	34	46	-

For simplification a shifting period of 3 hours during daytime and 12 hours during night time is assumed in a simulation scaling-up the ISET system to 6400 BEMIs. Furthermore, probabilities of the start time[12], the driving distance, which indicates the SOC- losses during a route and the driving time[13] are taken into account according to [MID, 2002]. Figure 2 shows an example for the load management of a PHEV carried out by the BEMI.

10 $t_{driving} = \text{average routes per day} * \text{average time per route}$

11 $t_{charging} = \frac{(\text{average routes per day } -1) * (\text{average routes length [km]} * \text{electricity consumption[kWh/km]})}{\text{connection power [KW]}}$

12 Data based on [2003 Tabellenband Mobilität in Deutschland] Table 7.1 B „Startzeit“ p.315.

13 Data based on [2003 Tabellenband Mobilität in Deutschland] Table 6 B „Länge des Weges“ p.313 and 7.3 A“ Wegdauer“ p.318.

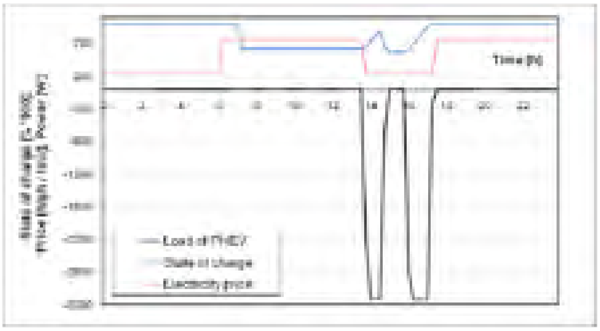

Figure 2: Demand-side management of a plug- in hybrid electric vehicle

Data basis: [MID 2002]: Assumptions: Connection power 3.2 kW, energy consumption 21 kWh/km, 10.2 kWh usable storage.

Energy distribution depending on fluctuating energy generation

Optimizing the utilization of fluctuating energy by demand-side management via price signals makes it necessary to predict the reaction of electric loads on the price. As a result of the learning algorithm Figure 4 shows the calculated power and the real power of a simulation with 6400 BEMIs each representing one household equipped with a washing machine, a cooling device and a PHEV.

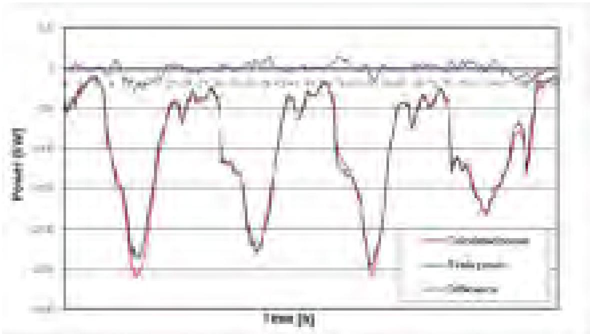

Figure 3: Calculated power of 6400 BEMIs

The calculation error is described by two indicators $\sigma_{est,real}$ / $P_{real,\ av}$[14] and $\sigma_{est,real}$ / σ_{Preal}[15]. Figure 5 shows these two indicators for the “reference” simulation equipped with a washing machine and a cooling device as well as for the reference simulation extended with PHEVs.

14 Standard deviation of the difference between the calculated power and the real power of the BEMI devices, as ration to the average real power. See [Nestle, 2008] p. 143.

15 Standard deviation of the difference between the calculated power and the real power of the BEMI devices, as ration to the average real power divided with the standard deviation of the real power. See [Nestle, 2008] p. 143.

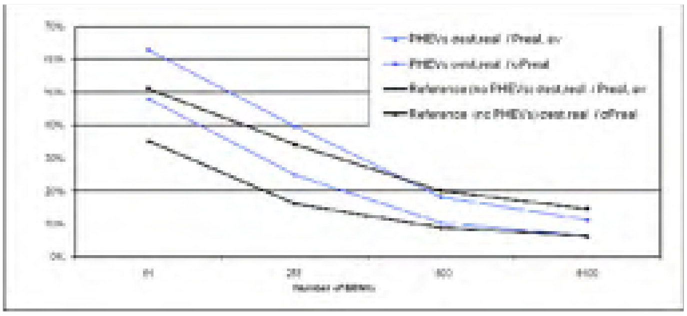

Figure 4: Calculation error with different numbers of BEMIs

It can be concluded that a higher number of BEMIs reduces the calculation error. The simulation of 6400 BEMIs extended with PHEVs shows similar or even better results than the reference simulation.

Indicators used describing the distribution of energy by the control station are $\sigma_{trader,real}$ / $P_{real,\ av}$ and $\sigma_{trader,real}$ / σ_{Preal} [16]. Figure 5 indicates that the energy distribution in the simulation extended with PHEVs leads to worse results compared to the reference simulation[17].

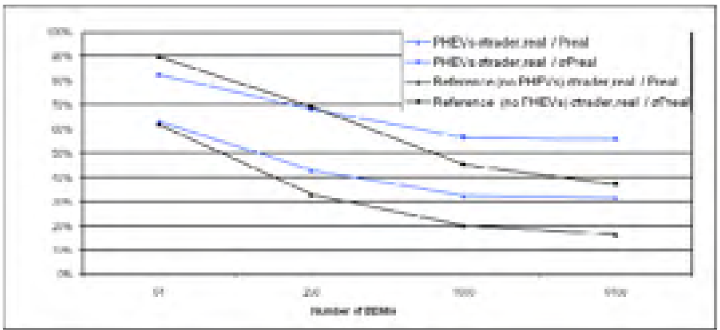

Figure 5: Energy distribution with different numbers of BEMIs

The reason for this effect is not clear, which makes further investigations necessary. A reason could be the bad match of the PV profile with the plug-in hybrid load profile and the small load shifting time during the day. A higher share of on- or offshore wind energy instead of PV will likely show better results distributing the energy of PHEVs

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16 [Nestle, 2008] p. 143

17 The difference between the energy provided by fluctuating energy generation or acquired as electricity blocks and the energy distributed to the BEMIs as well as their standard deviations should be minimized.

because of their feed-in characteristics. Furthermore, vehicle owner with a longer load shifting time during the day such as full- time employees could reduce the problem distributing energy during the day using energy from PV.

Conclusion

The demand-side management system using indirectly controlled, price-based distribution was able to accurately predict customer behaviour regarding the use of plug-in hybrid vehicles. However, the simulation indicates that it might be more complex to distribute the load of PHEVs to fit the profile of wind power and PV than was the case for the washing machines and refrigerators used as reference devices in the energy management system at ISET.

Figure 6 compares the additionally required energy with the share of fluctuating energy.

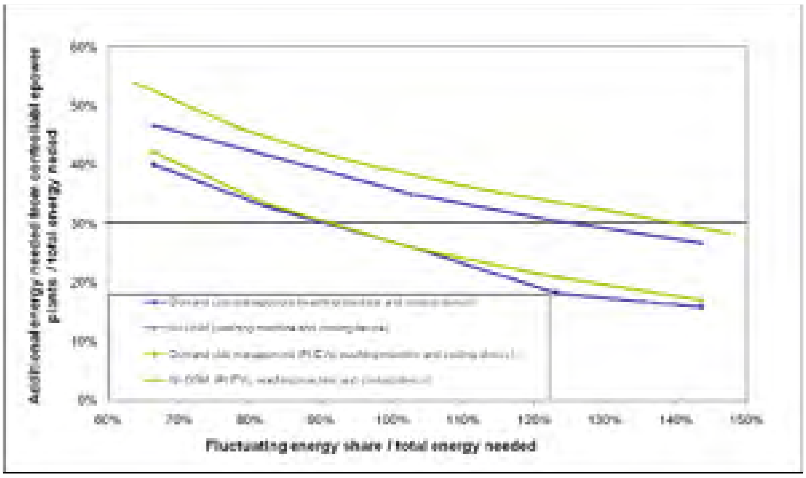

Figure 6: Controllable electricity needed with and without demand-side management

Overall, the demand-side management with PHEVs shows a similar reduction potential of additional power plants needed for balancing energy compared to the reference simulation limited to cooling devices and washing machines. Without management, the simulation extended by PHEVs requires more controllable energy than in the case of the reference simulation. The extended simulation in total shows an additional reduction of required controllable capacity of approximately 33 %.

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